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A Realistic Extension of Gauge-Mediated SUSY-Breaking Model with Superconformal Hidden Sector

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Abstract

The sequestering of supersymmetry (SUSY) breaking parameters, which is induced by superconformal hidden sector, is one of the solutions for the μ/B_μ problem in gauge-mediated SUSY-breaking scenario. However, it is found that the minimal messenger model does not derive the correct electroweak symmetry breaking. In this paper we present a model which has the coupling of the messengers with the SO(10) GUT-symmetry breaking Higgs fields. The model is one of the realistic extensions of the gauge mediation model with superconformal hidden sector. It is shown that the extension is applicable for a broad range of conformality breaking scale.

1 Introduction

Low-energy supersymmetry (SUSY) is a very attractive model of physics beyond the standard model (SM). In the minimal supersymmetric standard model (MSSM), however, general SUSY-breaking masses of squarks and sleptons induce too large FCNC and/or CP violation effects in low-energy observables. These SUSY FCNC and CP problems should be solved in realistic SUSY-breaking models.

Gauge-mediated SUSY breaking (GMSB) [1, 2, 3, 4, 5] is one of the promising mechanisms to describe the SUSY-breaking sector in the MSSM. The SUSY breaking is transmitted to the MSSM sector through the gauge interaction, which induces the flavor-blind SUSY-breaking masses of squarks and sleptons. The gaugino masses M_a ($a = 1-3$) are generated at one-loop level as $M_a \simeq \alpha_a/(4\pi) F_S/M_m$, and the sfermion mass squareds are induced by two-loop diagrams so that the sfermion masses are comparable to those for the gauginos. Here, M_m and F_S are the mass of the messenger and F-component vacuum expectation value (VEV) of the singlet superfield S in the hidden sector, respectively, and F_S/M_m is $\simeq$ 10-100 TeV.

One of the difficulties in the model building of GMSB is the origin of the B_μ term, which is the SUSY-breaking term corresponding to the supersymmetric mass of the MSSM Higgs doublets, μ. B_μ has the mass dimension two. From viewpoints of naturalness and electroweak symmetry breaking, B_μ and μ are required to be comparable to the other SUSY-breaking mass parameters in the MSSM. The correct size of μ is realized when μ is generated at one-loop level or even when the MSSM Higgs doublets are directly coupled with S in the superpotential with a small coupling ($\sim 10^{-(2-3)}$). However, if B_μ is simultaneously induced with μ, B_μ is relatively enhanced by a one-loop factor. This problem is sometimes called as the μ/B_μ problem. Several mechanisms are proposed for this problem [6, 7, 8, 9].

It is pointed out in Refs. [8, 9] that the μ/B_μ problem is solved in the GMSB models with the superconformal hidden sector (SCHS). The conformal sequestering suppresses B_μ, in addition to sfermion mass squareds $m^2_{\tilde{f}}$ ($f = q, u, d, l, e$) [10], relative to the A parameters and gaugino masses. The SUSY-breaking parameters at the scale M_X at

which the conformality is broken are given as [9]

$$
\begin{aligned}
m_{\tilde{f}}^2 &= 0,\ (f = q, u, d, l, e), \\
m_{H_u}^2 = m_{H_d}^2 &= -\mu^2,\ B_\mu = 0, \\
A_u = y_u A_{H_u},\ A_d &= y_d A_{H_d},\ A_l = y_l A_{H_d},
\end{aligned} \tag{1}
$$

where M_a $(a = 1-3) \simeq \mu \simeq A_{H_u} \simeq A_{H_d}$. Here, $m_{H_u}^2$ and $m_{H_d}^2$ are the SUSY-breaking mass squareds for the Higgs doublets, $y_{u/d/l}$ are the Yukawa couplings for up and down quarks and leptons, and $A_{u/d/l}$ are the A parameters for them. In addition to Eq. (1), a relationship $|A_{H_u} A_{H_d}| = |\mu|^2$ is also valid when the messenger sector is minimal. Though other arbitrary messenger sectors relax this relationship, it brings new sources of CP violation.

In this paper we discuss the electroweak symmetry breaking under the boundary condition for the SUSY-breaking parameters given in Eq. (1). It is found that the electroweak symmetry breaking conditions have no physical solution when the messenger sector is minimal and the GUT relation among the gaugino masses is imposed. We propose an extension of the minimal messenger model in which the messenger multiplets are coupled with the GUT-symmetry breaking sector in order to avoid the introducing CP violation.

It is shown that this extension makes the model phenomenologically viable and that it is applied for arbitrary scale for M_X.

The organization of the paper is as follows. In Section 2, we review the GMSB models with SCHS. We show that the minimal messenger model has no realistic vacuum with the electroweak symmetry broken. In Section 3, we propose an extension of the minimal model, which the messenger sector is coupled with the GUT-symmetry breaking Higgs VEV. Section 4 is devoted to conclusion.

2 GMSB Models with SCHS and Minimal Messenger Model

The gauge-mediated SUSY-breaking model with superconformal hidden sector has nontrivial prediction for the SUSY-breaking parameters at MSSM as in Eq. (1). Here, we review the derivation. See Ref. [9] for the detail.

We first discuss the gaugino and sfermion masses in the model as warming up. After decoupling of the messenger multiplets with the SM gauge quantum numbers, the following effective interactions for the gauge and matter multiplets in the MSSM with a singlet in the hidden sector S are generated,

$$\mathcal{L}_{eff} = \left\{ \int d^2\theta \sum_{a=1-3} \frac{1}{2} c_\lambda^a \frac{S}{M_m} \mathcal{W}^{a\alpha} \mathcal{W}_\alpha^a + h.c. \right\} - \int d^4\theta \sum_f c_{m^2}^f \frac{S^\dagger S}{M_m^2} \tilde{f}^\dagger \tilde{f}. \tag{2}$$

When S gets the F-term VEV, $\langle S \rangle \big|_{\theta^2} = F_S$, the first and second terms generate the gaugino and sfermion masses, respectively. The coefficients c_λ^a are at one-loop level while $c_{m^2}^f$ are at two-loop level. The explicit forms for them can be read off from formulae given in Ref. [11].

After the hidden sector enters into conformal regime at $\Lambda_\star$, above two terms receive huge radiative correction. At $\mu_R(< \Lambda_\star)$, the effective interactions are given as

$$\mathcal{L}_{eff} = \left\{ \int d^2\theta \sum_{a=1-3} \frac{1}{2} c_\lambda^a Z_S^{-1/2} \frac{S}{M_m} \mathcal{W}^{a\alpha} \mathcal{W}_\alpha^a + h.c. \right\} - \int d^4\theta \sum_f c_{m^2}^f Z_S^{-1} Z_{|S|^2} \frac{S^\dagger S}{M_m^2} \tilde{f}^\dagger \tilde{f}, \tag{3}$$

where

$$\begin{aligned} Z_S(\mu_R) &= \left(\frac{\Lambda_\star}{\mu_R} \right)^{3R(S)-2}, \\ Z_{|S|^2}(\mu_R) &= \left(\frac{\Lambda_\star}{\mu_R} \right)^{-\alpha_S}. \end{aligned} \tag{4}$$

Here, Z_S is the wave function renormalization of S and $R(S)$ is the R charge for S. When S is singlet under the hidden gauge groups, $R(S)$ is larger than $2/3$ so that $Z_S(\mu_R) > 1$. The 1PI contribution to operators $S^\dagger S$ is parametrized by α_S in the above equation.

The gaugino masses M_a at M_X, at which the conformality is broken, are given as

$$M_a = c_\lambda^a Z_S^{-1/2}(M_X) \frac{F_S}{M_m}. \tag{5}$$

When $\alpha_S > 0$, the sfermion masses are suppressed, and the conformal sequestering is realized as [10]

$$m_{\tilde{f}}^2 = 0, \ \ (f = q, u, d, l, e). \tag{6}$$

Next, let us move to the Higgs sector. Here, the messenger sector is assumed to be minimal among models where the μ term is generated by one-loop diagrams. Then, the messenger multiplets are embedded in SU(5) **10** and **10***-dimensional multiplets.[1] The messenger multiplets have an interaction with the Higgs doublets H_u and H_d in the superpotential,

$$W = \lambda_u H_u Q_m U_m + \lambda_d H_d \bar{Q}_m \bar{U}_m + (\kappa S + M_m)(Q_m \bar{Q}_m + U_m \bar{U}_m + E_m \bar{E}_m), \tag{7}$$

where Q_m, U_m, and E_m ($\bar{Q}_m$, $\bar{U}_m$, and $\bar{E}_m$), which come from the SU(5) **10** (**10***) multiplet, have SU(5) symmetric mass and interaction terms.

Integration of the messenger sector leads to the effective interactions of the Higgs doublets with S as

$$\begin{aligned}
\mathcal{L}_{eff} &= -\int d^4\theta \left\{ c_\mu \frac{S^\dagger}{M_m} H_d H_u + c_{B_\mu} \frac{S^\dagger S}{M_m^2} H_d H_u \right. \\
&\quad \left. + c_{A_u} \frac{S}{M_m} H_u^\dagger H_u + c_{A_d} \frac{S}{M_m} H_d^\dagger H_d + h.c. \right\} \\
&\quad - \int d^4\theta \left\{ c_{m^2}^{H_u} \frac{S^\dagger S}{M_m^2} H_u^\dagger H_u + c_{m^2}^{H_d} \frac{S^\dagger S}{M_m^2} H_d^\dagger H_d \right\}.
\end{aligned} \tag{8}$$

Here, the coefficients of the operators, c_μ, c_{B_μ}, c_{A_u}, and c_{A_d} are generated at one-loop level,

$$\begin{aligned}
c_\mu &= -3\frac{\lambda_u \lambda_d}{(4\pi)^2}\kappa^*, \qquad c_{B_\mu} = -3\frac{\lambda_u \lambda_d}{(4\pi)^2}|\kappa|^2, \\
c_{A_u} &= +3\frac{|\lambda_u|^2}{(4\pi)^2}\kappa, \qquad c_{A_d} = +3\frac{|\lambda_d|^2}{(4\pi)^2}\kappa,
\end{aligned} \tag{9}$$

while $c_{m^2}^{H_u}$ and $c_{m^2}^{H_d}$ are vanishing at one-loop level.

[1] Even when the messengers are SU(5) **5** and **5***-dimensional multiplets, the μ term is generated if additional SU(5) singlets are also introduced. However, when the singlets are coupled with S, the arbitrary phases in the interactions generate CP-violating phases in the A and B_μ terms.

After the hidden sector enters into conformal regime, the effective interactions become

$$
\begin{aligned}
\mathcal{L}_{eff} &= -\int d^4\theta \left\{ c_\mu Z_S^{-1/2} \frac{S^\dagger}{M_m} H_d H_u \right. \\
&\left. + Z_S^{-1} \left[Z_{|S|^2} c_{B_\mu} + (Z_{|S|^2} - 1)(c_\mu c_{A_u} + c_\mu c_{A_d}) \right] \frac{S^\dagger S}{M_m^2} H_d H_u + h.c. \right\} \\
&- \int d^4\theta \left\{ c_{A_u} Z_S^{-1/2} \frac{S}{M_m} H_u^\dagger H_u + h.c. \right. \\
&\left. + Z_S^{-1} \left[Z_{|S|^2} c_{m^2}^{H_u} + (Z_{|S|^2} - 1)(|c_{A_u}|^2 + |c_\mu|^2) \right] \frac{S^\dagger S}{M_m^2} H_u^\dagger H_u + (H_u \leftrightarrow H_d) \right\}. \quad (10)
\end{aligned}
$$

The terms proportional to $(Z_{|S|^2} - 1)$ come from diagrams with the Higgs doublet exchange. Since the tree-level diagrams with the Higgs exchange do not contribute to the effective Lagrangian, one is subtracted from $Z_{|S|^2}$ there. Therefore, the SUSY-breaking terms in the Higgs sector at M_X are

$$
\begin{aligned}
m_{H_u}^2 = m_{H_d}^2 = -\mu^2, \ B_\mu = 0, \\
A_u = y_u A_{H_u}, \ A_d = y_d A_{H_d}, \ A_l = y_l A_{H_d}, \qquad (11)
\end{aligned}
$$

when $Z_{|S|^2}(M_X) \ll 1$. Here,

$$
\begin{aligned}
\mu &= c_\mu Z_S^{-1/2} \frac{F_S^\dagger}{M_m} = -3 \frac{\lambda_u \lambda_d}{(4\pi)^2} Z_S^{-1/2} \frac{\kappa^* F_S^\dagger}{M_m}, \\
A_{H_u/H_d} &= -c_{A_{u/d}} Z_S^{-1/2} \frac{F_S}{M_m} = -3 \frac{|\lambda_{u/d}|^2}{(4\pi)^2} Z_S^{-1/2} \frac{\kappa F_S}{M_m}. \qquad (12)
\end{aligned}
$$

In the derivation of Eq. (11), we redefined the Higgs doublets as $H_{u/d} - c_{A_{u/d}} Z_S^{-1/2} \frac{S}{M_m} H_{u/d} \to H_{u/d}$. Since we now derived the SUSY-breaking terms in the minimal messenger model, Eq. (12) satisfies the relationship $|A_{H_u} A_{H_d}| = |\mu|^2$. In Appendix we give formulae for the SUSY-breaking terms of the Higgs sector in more general messenger cases.

Now we discuss the electroweak symmetry breaking in the GMSB models with SCHS. The minimization condition of the Higgs potential at tree level results in

$$
\sin 2\beta = -\frac{2B_\mu}{m_1^2 + m_2^2}, \qquad (13)
$$

$$
m_Z^2 = -\frac{m_1^2 - m_2^2}{\cos 2\beta} - (m_1^2 + m_2^2), \qquad (14)
$$

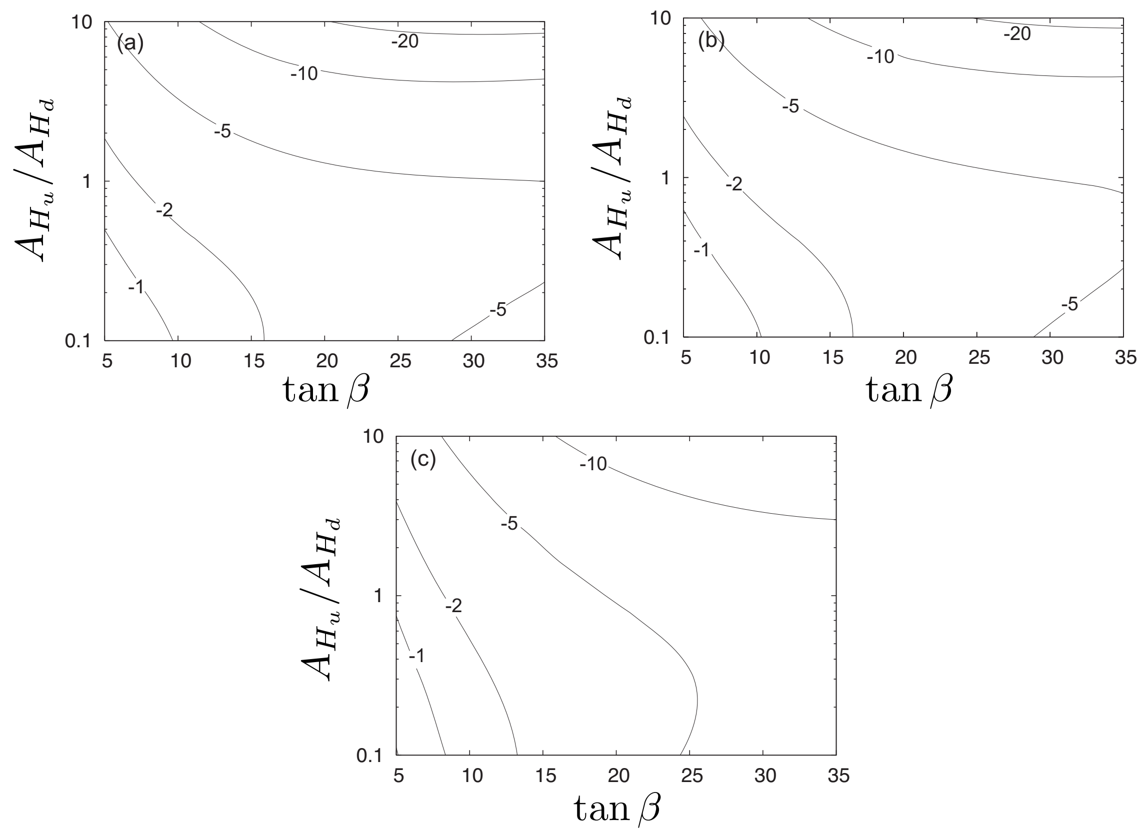

Figure 1: m_A^2/μ^2 as a function of A_{H_u}/A_{H_d} and $\tan\beta$. We take $M_X = 10^{14}$ GeV in (a), $M_X = 10^{10}$ GeV in (b), and $M_X = 10^6$ GeV in (c).

where $m_1^2 \equiv (m_{H_d}^2 + \mu^2)$ and $m_2^2 \equiv (m_{H_u}^2 + \mu^2)$. In the GMSB models with SCHS, the Higgs boson mass squareds are zero at tree level even after including the supersymmetric mass μ. Thus, the electroweak symmetry breaking and the stability of the Higgs boson potential are sensitive to the radiative corrections to them.

In Fig. 1 we show the pseudo-scalar Higgs mass squared $m_A^2(\equiv m_1^2 + m_2^2)$ normalized by μ^2 as a function of A_{H_u}/A_{H_d} and $\tan\beta$ in the minimal messenger model. We take $M_X = 10^{14}$ GeV in (a), $M_X = 10^{10}$ GeV in (b), and $M_X = 10^6$ GeV in (c), and m_A^2/μ^2 is evaluated at $m_{SUSY} = 1$ TeV. Here, the messengers have SU(5) symmetric mass terms so that the gaugino masses obey the GUT relation. In the minimal model, the input parameters are the gluino mass M_3, μ and A_{H_u}/A_{H_d} in addition to M_X, two of which are fixed by two Higgs VEVs. Eq. (13) determines the ratio of μ and M_3, and then m_A^2/μ^2.

It is found from Fig. 1 that m_A^2 is always negative. This implies that the vacuum is not stabilized. In order to qualitatively understand this result, we derived approximation of the mass parameters in the Higgs potential from the renormalization-group equations (RGE) as

$$\begin{aligned} m_1^2 \equiv (m_{H_d}^2 + \mu^2)(m_{SUSY}) &= (3\alpha_2 + \alpha_Y)\mu^2 t_{SUSY} + (3\alpha_2 M_2^2 + \alpha_Y M_1^2) t_{SUSY} \\ &\quad -3\alpha_t \mu^2 t_{SUSY}, \\ m_2^2 \equiv (m_{H_u}^2 + \mu^2)(m_{SUSY}) &= (3\alpha_2 + \alpha_Y)\mu^2 t_{SUSY} + (3\alpha_2 M_2^2 + \alpha_Y M_1^2) t_{SUSY} \\ &\quad -3\alpha_t A_{H_u}^2 t_{SUSY} - 16\alpha_3\alpha_t (M_3^2 + A_{H_u} M_3) t_{SUSY}^2, \\ B_\mu/\mu(m_{SUSY}) &= (3\alpha_2 M_2 + \alpha_Y M_1 - 3\alpha_t A_{H_u}) t_{SUSY} \\ &\quad -8\alpha_t\alpha_3 M_3 t_{SUSY}^2, \end{aligned} \tag{15}$$

where $t_{SUSY} = \log(M_X/m_{SUSY})/2\pi$, $\alpha_t(\equiv y_t^2/4\pi)$ and α_a $(a = Y, 2, 3)$ are for the top-quark Yukawa and gauge coupling constants, respectively. Here, we include the one-loop contributions due to the electroweak and top-quark Yukawa interactions and two-loop contributions due to the strong one. The later one is comparable to the one-loop terms when the gluino mass is larger than others, as in the GUT relation. These equations are semi-quantitatively valid when $\alpha_a t_{SUSY}$, $\alpha_t t_{SUSY} \ll 1$. Even when $\alpha_a t_{SUSY}$,$\alpha_t t_{SUSY} \sim O(1)$, we can guess the qualitative behaviors, such as relative signs and sizes among the terms, using the equations.

It is found that A_{H_u/H_d} are negative in Eq. (12). This implies that the one-loop contributions to B_μ/μ are constructive. Sizable values of B_μ/μ lead to suppression of μ/M_3 from Eq. (13) for $\tan\beta \gtrsim 1$. In those cases the two-loop contribution, which enhanced by the gluino mass, derives m_A^2 to be negative. When $\tan\beta \simeq 1$, $\mu/M_3 \sim 1$ is possible. However, it is found from the figure that m_A^2 is still negative.

One of the solutions for the problem is introduction of non-zero B_μ at M_X. If $Z_{|S|^2}(M_X)$ is *accidentally* around $O(10^{-(2-3)})$, B_μ keeps its sizable value at M_X. However, its sign is positive relatively to μ since

$$B_\mu = -3\frac{\lambda_u\lambda_d}{(4\pi)^2} Z_S^{-1} Z_{|S|^2} \frac{|\kappa|^2 |F_S|^2}{M_m^2}. \tag{16}$$

This is constructive to the RGE contribution to B_μ, while the deconstructive interference is rather required for the electroweak symmetry breaking. This is also noticed in Ref. [12].

If the operator $S^\dagger S$ is mixed with other operators whose D-component VEVs are non-vanishing, the sign of the contribution to B_μ may be changed.

The second solution is extension of the messenger sector. When introducing multiple messengers with different supersymmetric masses and couplings with S, the deconstructive interference in B_μ is possible. However, arbitrary introduction of the messengers leads to CP phases in the SUSY-breaking parameters. That is not favored from phenomenological viewpoints.

3 Extension

One of the extensions of the GMSB with SCHS without introducing CP violation is introduction of coupling of the messengers with the GUT-symmetry breaking Higgs fields. Let us consider following superpotential;

$$W = \lambda_u H_u \psi\psi + \lambda_d H_d \bar{\psi}\bar{\psi} + (\kappa S + \zeta\Sigma)\bar{\psi}\psi. \tag{17}$$

Here, ψ and $\bar{\psi}$ are the messengers and Σ is the GUT-symmetry breaking Higgs fields. The messengers are **10** and **10***-dimensional multiplets in the SU(5) GUTs, and **16** and **16*** in the SO(10) GUTs.

It is found that this extension does not work well in the SU(5) GUTs. When the SU(5) breaking Higgs field is a **24**-dimensional multiplet, the messenger masses are proportional to their hypercharges so that the bino mass is zero at one-loop level. When the SU(5) breaking Higgs field is a **75**-dimensional multiplet, the SU(2) doublet messenger quark and singlet messenger quark masses are degenerate with the opposite sign. Then, μ and A parameters are zero at one-loop level.

These problems are resolved when the messenger masses are generated by the higher-dimensional operators with Σ. In those cases the colored messengers are relatively lighter so that the gluino becomes heavier. From the electroweak symmetry breaking condition in Eq. (14), which is reduced $m_Z^2 \simeq -2m_2^2$ for $\tan\beta \gtrsim 1$, larger M_3 leads to larger μ. However, $m_A^2 (\simeq m_1^2 - 1/2 m_Z^2)$ is likely to be tachyonic due to large μ.

Thus, we consider the SO(10) GUTs. Here, we assume that Σ is a **45**-dimensional multiplet. The messenger masses are given by hypercharge Q_Y and $(B-L)$ charge of the

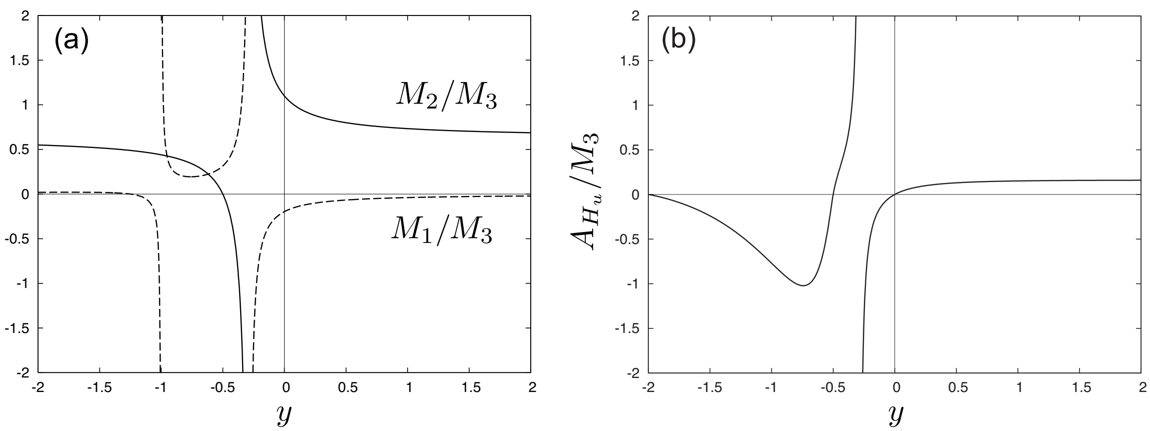

Figure 2: Ratios M_2/M_3 and M_1/M_3 at 1 TeV (a) and A_{H_u}/M_3 at M_X (b) as functions of $y(\equiv M_Y/M_{B-L})$. Here, $\lambda_u = g_3$ for simplicity.

messengers Q_{B-L} [2], because

$$\zeta\langle\Sigma\rangle \;=\; Q_Y M_Y + Q_{B-L} M_{B-L}. \tag{18}$$

In the following, we consider a case where only the SU(5) **10** and **10***-dimensional components of the **16** and **16***-dimensional multiplets become effective in generation of the SUSY-breaking terms in the MSSM. This is only for simplicity, because when the SO(10) full multiplets contribute to SUSY-breaking mediation, the M_Y/M_{B-L} dependence of soft breaking parameters is more complicated. Actually, it is realized when an SO(10) **10**-dimensional multiplet is introduced in the messenger sector. In that case, we can add following terms to the superpotential,

$$W \;=\; f_u \psi\phi\psi_H + f_d \bar{\psi}\phi\bar{\psi}_H + \frac{1}{2} M\phi\phi, \tag{19}$$

where $\psi_H(\bar{\psi}_H)$ are **16**(**16***)-dimensional multiplets and ϕ is a **10**-dimensional matter multiplet. The SU(5) **5** and **5*** multiplets of **16** and **16*** are decoupled when SU(5) singlets of ψ_H and $\bar{\psi}_H$ have non-zero vacuum expectation values.

In Fig. 2 ratios M_2/M_3 and M_1/M_3 at 1 TeV and A_{H_u}/M_3 at M_X are shown as functions of $y(\equiv M_Y/M_{B-L})$. Notice that when $y > 0$, A_{H_u}/M_3 is positive and gluino is lighter

[2] In this paper, the assignment of $(B-L)$ charges for quarks and leptons are 1/3 and (-1), respectively.

than twice the mass of wino. These are welcome to the electroweak symmetry breaking as discussed above. In fact, we could easily find the solutions which are phenomenologically viable. We studied the other regions. However, though we found points to be consistent with the electroweak symmetry breaking conditions, their spectrums are quite light so that they are experimentally excluded.

We show mass spectra and the branching ratio $\mathrm{BR}(b \to s\gamma)$ at several points, $M_X = 10^8, 10^{11}$, and 10^{14} GeV, in Table 1 using SuSpect 2.41 [13] and SusyBSG 1.1.2 [14]. All of them are consistent with the Higgs boson mass bound, sparticle mass bounds [15] and branching ratio of $b \to s\gamma$ [16];

$$\mathrm{Br}(b \to s\gamma) = (355 \pm 24^{+9}_{-10} \pm 3) \times 10^{-6}. \tag{20}$$

In all sample points, the right-handed slepton masses are very small compared with other sparticle masses. As we have seen in Eq. (1), the scalar fermion soft masses are nearly zero at M_X. In addition, when $y > 0$, the bino is light compared to the wino and gluino. As a result, the right-handed slepton masses are such small in this model.

Using SuSpect 2.34, we also calculated supersymmetric contributions to the anomalous magnetic moment of the muon, $a_\mu = (g-2)_\mu/2$. The comparison between the measurements [17] and the SM theoretical predictions [18] for a_μ is

$$\Delta a_\mu = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} = (30.2 \pm 8.7) \times 10^{-10}. \tag{21}$$

The left-handed sleptons are so heavy that the SUSY contribution to a_μ is suppressed. When the deviation is confirmed in future, this model would be disfavored.

4 Conclusion

We have studied the electroweak symmetry breaking for the GMSB models with SCHS which solve the μ/B_μ problem by the conformal sequestering. It is found that the correct electroweak symmetry breaking is not derived in the minimal messenger model with GUT relation among the gaugino masses.

In this paper we also propose an extension of the minimal model which has the coupling of the messengers with the SO(10) GUT-symmetry breaking Higgs fields. This is one of

$\tan\beta$	10	10	10
y	0.281	0.150	0.0452
A_{H_u}/A_{H_d}	11.5	7.16	1.00
M_X	10^8 [GeV]	10^{11} [GeV]	10^{14} [GeV]
$\widetilde{g}$	2906	1553	1304
$\widetilde{\chi}_1^\pm$	1049	918.9	354.8
$\widetilde{\chi}_2^\pm$	2637	1443	1303
$\widetilde{\chi}_1^0$	293.3	191.8	203.7
$\widetilde{\chi}_2^0$	1049	918.1	354.0
$\widetilde{\chi}_3^0$	1052	925.3	365.1
$\widetilde{\chi}_4^0$	2637	1443	1303
$\widetilde{t}_1$	1777	1013	758.4
$\widetilde{t}_2$	2255	1424	1319
$(\widetilde{u},\widetilde{c})_{L,R}$	2330, 2030	1477, 1223	1403, 1077
$\widetilde{b}_1$	2024	1218	1066
$\widetilde{b}_2$	2238	1403	1303
$(\widetilde{d},\widetilde{s})_{L,R}$	2331, 2029	1479, 1223	1405, 1075
$\widetilde{\tau}_1$	98.41	101.3	128.5
$\widetilde{\tau}_2$	1132	825.7	904.6
$(\widetilde{e},\widetilde{\mu})_{L,R}$	1132, 104.6	825.5, 102.7	906.1, 148.0
$\widetilde{\nu}_\tau$	1129	821.9	901.3
$\widetilde{\nu}_{e,\mu}$	1129	821.9	902.7
h	117.8	115.4	114.5
H	1142	810.2	903.0
A	1142	809.9	902.8
$H^\pm$	1145	814.1	906.7
BR$(b\to s\gamma)$	3.41×10^{-4}	3.68×10^{-4}	3.77×10^{-4}
Δa_μ	-1.17×10^{-10}	-1.29×10^{-10}	-4.86×10^{-10}

Table 1: Sparticle and Higgs boson mass spectra (in units of GeV) in $m_t = 171.2$ GeV.

the minimal extension to realize a realistic model without introducing CP violation in the SUSY-breaking terms. The extended messenger sector allows us to change the gaugino mass relation and the signs of A and B_μ parameters. Thus, the model can induce the correct electroweak symmetry breaking even if the B_μ is significantly suppressed ($B_\mu = 0$) at the conformality breaking scale, M_X. Moreover, the model can be applied for a broad range of the M_X. In a case where all but the SU(5) **10** and **10*** multiplets of the **16** and **16*** are decoupled, for example, we have presented mass spectra in several values of M_X. They are consistent with the lightest Higgs boson mass bound, sparticle mass bounds, and branching ratio of $b \to s\gamma$.

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Appendix

Here, we give formulae for the SUSY-breaking terms of the Higgs sector in the following messenger model,

$$W = \lambda_u H_u \phi_1 \phi_2 + \lambda_d H_d \bar{\phi}_1 \bar{\phi}_2 + (\kappa_1 S + M_1)\phi_1 \bar{\phi}_1 + (\kappa_2 S + M_2)\phi_2 \bar{\phi}_2 \tag{22}$$

where $\phi_{1,2}$ and $\bar{\phi}_{1,2}$ are the messengers, and S is a singlet in the hidden sector, which acquires a non-zero F-component VEV, $\langle S \rangle\big|_{\theta^2} = F_S$, at the SUSY-breaking scale. After integrating out the messengers, this SUSY-breaking VEV generates μ, B_μ, A terms, and the gaugino masses. The SUSY-breaking terms of the Higgs sector are parametrized as

$$\begin{aligned} V &= m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + (B_\mu H_d H_u + h.c.) \\ &\quad + (A_{H_u} f_u u H_u Q + A_{H_d} f_d d H_d Q + A_{H_d} f_e e H_d L + h.c.). \end{aligned} \tag{23}$$

The μ, B_μ, and A terms are given as

$$\begin{aligned}
\mu &= -\frac{\lambda_u\lambda_d}{(4\pi)^2}\left[x_{21}\ g(x_{21})\frac{\kappa_1^* F_S^*}{M_1} + x_{12}\ g(x_{12})\frac{\kappa_2^* F_S^*}{M_2}\right], \\
B_\mu &= -\frac{\lambda_u\lambda_d}{(4\pi)^2}\left[f_1(x_{21})\frac{|\kappa_1 F_S|^2}{M_1^2} + f_1(x_{12})\frac{|\kappa_2 F_S|^2}{M_2^2}\right. \\
&\quad \left. + f_2(x_{21})\frac{\kappa_1^*\kappa_2|F_S|^2}{M_1^2} + f_2(x_{12})\frac{\kappa_1\kappa_2^*|F_S|^2}{M_2^2}\right], \\
A_{H_u} &= -\frac{|\lambda_u|^2}{(4\pi)^2}\left[g(x_{21})\frac{\kappa_1 F_S}{M_1} + g(x_{12})\frac{\kappa_2 F_S}{M_2}\right], \\
A_{H_d} &= -\frac{|\lambda_d|^2}{(4\pi)^2}\left[g(x_{21})\frac{\kappa_1 F_S}{M_1} + g(x_{12})\frac{\kappa_2 F_S}{M_2}\right],
\end{aligned} \tag{24}$$

where the supersymmetric messenger masses M_1 and M_2 are taken real, and $x_{12} = M_1/M_2$. The mass functions $g(x)$, $f_1(x)$ and $f_2(x)$ are

$$\begin{aligned}
g(x) &= \frac{1}{(1-x^2)^2}(1 - x^2 + x^2\log x^2), \\
f_1(x) &= \frac{1}{(1-x^2)^3}x(1 - x^4 + 2x^2\log x^2), \\
f_2(x) &= -\frac{1}{(1-x^2)^3}x^2(2(1-x^2) + (1+x^2)\log x^2).
\end{aligned} \tag{25}$$

These three functions are positive definite.

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